USNO Analysis Center for Source Structure Report

Alan L. Fey, David A. Boboltz, Ralph A. Gaume, Kerry A. Kingham

Abstract

This report summarizes the activities of the United States Naval Observatory Analysis Center for Source Structure for calendar year 2004. VLBA RDV experiment RDV45 was calibrated and imaged. VLBA high frequency (24 & 43 GHz) experiments BL115B and BL115C were calibrated and imaged. A new method for quantifying source structure was developed. Although initially applied to the high frequency data, the method is easily adapted to the study of ICRF sources at the standard frequencies. A Southern Hemisphere imaging and astrometry program for maintenance of the ICRF continued. Imaging of an additional 60 southern hemisphere ICRF sources at 8.4 GHz was completed. Activities planned for the year 2005 include continued imaging of ICRF sources at standard and higher frequencies and continued analysis of source structure and its variation.

1. Analysis Center Operation

The Analysis Center for Source Structure is supported and operated by the United States Naval Observatory (USNO). The charter of the Analysis Center is to provide products directly related to the IVS determination of the "definition and maintenance of the celestial reference frame." These include, primarily, radio frequency images of ICRF sources, intrinsic structure models derived from the radio images, and an assessment of the astrometric quality of the ICRF sources based on their intrinsic structure.

The web server for the Analysis Center is hosted by the USNO and can be accessed by pointing your browser to

`http://rorf.usno.navy.mil/ivs_saac/`

The primary service of the analysis center is the Radio Reference Frame Image Database (RRFID), a web accessible database of radio frequency images of ICRF sources. The RRFID contains 3285 Very Long Baseline Array (VLBA) images of 463 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 783 images of 231 sources at frequencies of 24 GHz and 43 GHz. The RRFID can be accessed from the Analysis Center web page or directly at

`http://www.usno.navy.mil/RRFID/`

A recent addition to the RRFID are Australian Long Baseline Array (LBA) images of 69 southern hemisphere ICRF sources at a radio frequency of 8.4 GHz.

2. Current Activities

2.1. RDV Imaging

VLBA experiment RDV45 (2004JUL14) was calibrated and imaged, adding 160 (80 S-band; 80 X-band) images to the RRFID including images of 11 sources (0316+413, 0426+273, 0602+673, 0620+389, 0656+082, 1030+074, 1226+023, 1240+381, 1417+385, 1738+499, 2235+731) not previously imaged. Unlike previous RDV experiments, the data from the geodetic antennas were flagged before processing leaving only the data obtained by the VLBA. This was done in an attempt to reduce the amount of time required to image these experiments by decreasing the amount of data actually used for imaging. The resultant images are essentially VLBA only but in some instances have lower resolution due to the sub-netting of the array during the RDV observations. A comparison of the angular resolution of the images with previous experiments showed that on average the resolution of the RDV45 images is about a factor of 1.6 times worse than for a full RDV experiment and about a factor of 1.1 times worse than for a VLBA only experiment (i.e. a VLBA experiment with no sub-netting). The consensus opinion reached was that the resulting lower resolution images would hinder structure analysis. Future RDV experiments will be processed with all available data.

2.2. VLBA High Frequency Imaging

VLBA observations to extend the ICRF to K-band (24 GHz) and Q-band (43 GHz) continued in 2004. These observations are part of a joint program between the National Aeronautics and Space Administration, the USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. During the calender year 2004, two VLBA high frequency experiments (BL115B and BL115C) were calibrated and imaged.

2.3. Quantifying Source Structure

The images from the RRFID can be used to classify the sources in terms of their suitability for astrometric use based on their spatial compactness. The CLEAN component model from an image is used to calculate the visibility amplitude, $V(r, \phi)$, in the u,v plane at 24 equally spaced baseline position angles, ϕ, spanning 180° and at 300 equally spaced u,v radii, r, (i.e. baseline lengths) ranging from zero to one Earth diameter.

The visibility amplitude is then averaged over baseline position angle at each u,v radii and then normalized by the zero spacing amplitude. The result is an estimate, $\bar{V}(r)/V(0)$, of the "average" visibility amplitude change as a function of baseline length, r.

The next step is to calculate the standard deviation, $\sigma_V(r)$, over all baseline position angles, ϕ, for each u,v radii and then divide $\sigma_V(r)$ by $\bar{V}(r)$ at each u,v radii. The result is a normalized estimate, $\sigma_V(r)/\bar{V}(r)$, of the azimuthal asymmetry of the source, i.e. if the source is mostly circular, then $\sigma_V(r)/\bar{V}(r)$ at all baseline lengths, r, will be small. If the source is highly elliptical, then $\sigma_V(r)/\bar{V}(r)$ will become increasingly larger with increasing baseline length.

Finally, we calculate an estimate of the radio astrometric quality of the observed sources. For each observed source, a score is tabulated based on the following (higher scores are better):

- **compactness**: range $[0-20]$, *i.e.*, $20 \times [\bar{V}(r_1)/V(0)]$ where r_1 is the u,v radius at which $\bar{V}(r)/V(0)$ reaches a minimum ($r_1 \leq r_x$)
- **asymmetry**: range $[0-40]$, *i.e.*, $40 \times [1 - \sigma_V(r_2)/\bar{V}(r_2)]$ where r_2 is the u,v radius at which $\sigma_V(r)/\bar{V}(r)$ reaches a maximum ($r_2 \leq r_x$)
- **baseline**: range $[0-40]$, *i.e.*, $40 \times [r_x/r_{max}]$ where r_x is the u,v radius at which the normalized "average" visibility and its normalized variation first intersect (eg. see Figure 1c,d) and r_{max} is the maximum u,v radius

The last step is to sum the score for each source. The result is our estimate of radio astrometric

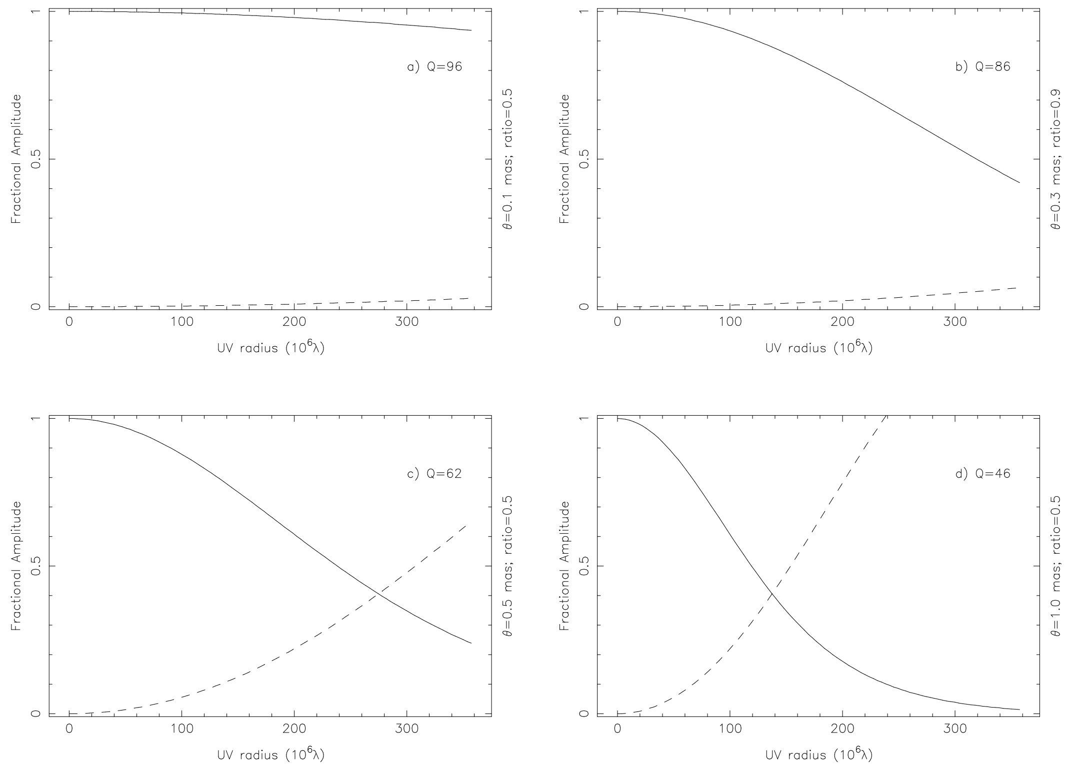

Figure 1. Normalized "average" visibility, $\bar{V}(r)/V(0)$ (solid line), and its normalized variation, $\sigma_V(r)/\bar{V}(r)$ (dashed line), calculated at an observing frequency of 8.4 GHz. Source models are single Gaussian components with a) angular size, $\theta = 0.1$ mas, axial ratio, R=0.5; b) $\theta = 0.3$ mas, R=0.9; c) $\theta = 0.5$ mas, R=0.5; d) $\theta = 1.0$ mas, R=0.5. Q is our estimate of the radio astrometric quality which ranges from zero (for the worst astrometric sources) to one hundred (for the best astrometric sources).

quality, Q, and ranges from zero (for the worst astrometric sources) to one hundred (for the best astrometric sources).

Examples of $\bar{V}(r)/V(0)$ and $\sigma_V(r)/\bar{V}(r)$ calculated at an observing frequency of 8.4 GHz for several simple source models are shown in **Figure 1**. An example for the source $0138-097$ at epoch 2004Feb15 is shown in **Figure 2**.

Initially applied to the high frequency (K/Q-band) data, the method has not yet been applied to the study of ICRF sources at the standard frequencies.

2.4. ICRF Maintenance in the Southern Hemisphere

The USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional S/X-band bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of $\delta = -20°$.

VLBI images for a total of 69 Southern Hemisphere ICRF sources at a frequency of 8.4 GHz

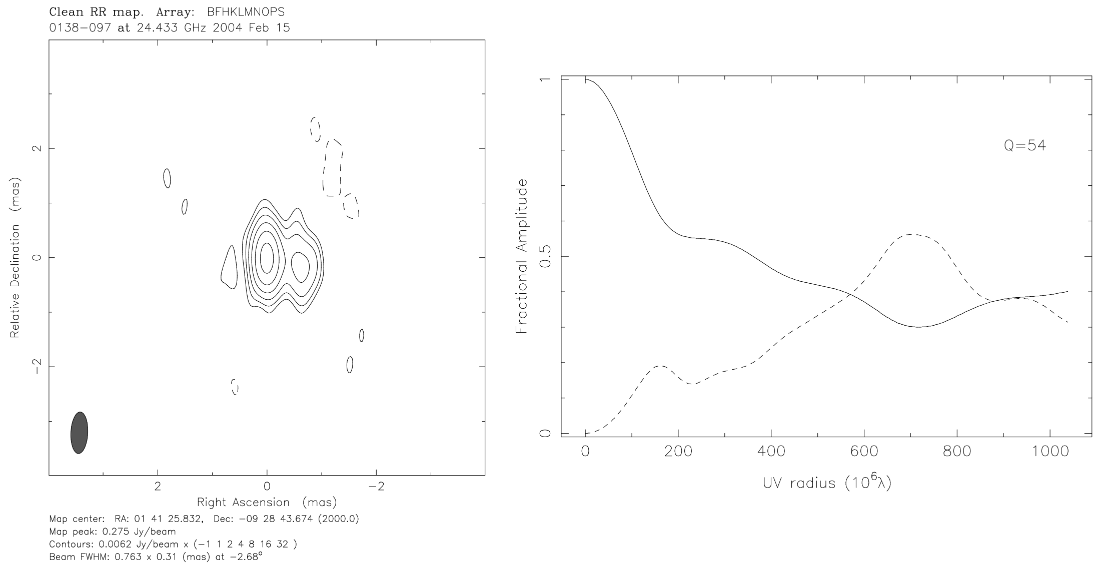

Figure 2. Contour plot of the radio emission at K-band (24 GHz) from the source 0138 − 097 at epoch 2004Feb15; *Right panel*: Normalized "average" visibility, $\bar{V}(r)/V(0)$, (solid line) and its normalized variation, $\sigma_V(r)/\bar{V}(r)$, (dashed line) for the same source.

using the Australian Long Baseline Array were published by Ojha, et al. (2004, AJ, 127, 3609). The images were used to calculate a core fraction, i.e., the ratio of core flux density to total flux density, for all observed sources. The resulting distribution, with a mean value of 0.83, suggests that most sources are relatively compact. However, just over half the observed sources show significant extended emission in the form of multiple compact components. Images for an additional 60 sources have been made and are being prepared for publication.

3. Staff

The staff of the Analysis Center is drawn from individuals who work at the USNO. The staff are: Alan L. Fey, David A. Boboltz, Ralph A. Gaume and Kerry A. Kingham.

4. Future Activities

The Analysis Center currently has a program of active research investigating the effects of intrinsic source structure on astrometric position determination. Results of this program are published in the scientific literature.

The following activities for 2005 are planned:

- Continue imaging and analysis of VLBA 2.3/8.4/24/43 GHz experiments
- Make additional astrometric and imaging observations in the Southern Hemisphere in collaboration with ATNF partners
- Extend structure analysis to 2.3/8.4 GHz experiments